



NASA SBIR Select 2012 Phase I Solicitation

E3.02 Advanced Technology Telescope for Balloon Mission

Lead Center: MSFC

Participating Center(s): GSFC, JPL

The purpose of this sub-topic is to mature demonstrated component level technologies (TRL4) to demonstrated system level technologies (TRL6) by using them to manufacture complete telescope systems. Examples of desired technological advances relative to the current state of the art include, but are not limited to:

- Reduce the areal cost of telescope by 2X such that larger collecting areas can be produced for the same cost or current collecting areas can be produced for half the cost.
- Reduce the areal density of telescopes by 2X such that the same aperture telescopes have half the mass of current state of art telescope. Less mass enables longer duration flights.
- Improve thermal/mechanical wavefront stability and/or pointing stability by 2X to 10X.

Technological maturation will be demonstrated by building one or more complete telescope assemblies which can be flown on potential long duration balloon experiments to do high priority science. Potential missions can cover any spectral range from X-rays to far-infrared/sub-millimeter. Potential telescopes include, but are not limited to:

- High-Energy Telescope.
- Ultra-Stable 1-meter Class UVOIR Telescope.
- Low-Cost CMB Telescopes.
- Low-Cost Far-Infrared Telescopes.
- Cryogenic Far-Infrared Telescope.
- 5 to 10 meter Segmented Far-IR Telescope.
- Heliophysics UVOIR Telescope.

Deliverable for Phase I is a reviewed preliminary design demonstrating feasibility. Deliverable for Phase II is a fully integrated and tested telescope assembly, ready to be incorporated into a potential balloon mission payload. In all cases, the telescopes must be designed to survive balloon environments, including 150K to 330K temperature range and 10G shock. The mass budgets for each telescope are nominal. Successful proposals will demonstrate an understanding of how the engineering specifications of their telescope meets the performance requirements and operational envelop of a potential balloon science mission; and presents a credible plan to build the proposed telescope. Please note, for this sub-topic a telescope is defined as a complete integrated system of optical and structural components which collects and concentrates electro-magnetic photons/waves for detection by a scientific imaging and/or spectroscopic instrument. See Technical Challenges for baseline technical requirements for potential telescopes. The 2010 National Academy Astro2010 Decadal Report recommended increased use of sub-orbital balloon-borne observatories. Two specific needs include:

- Far-IR telescope systems for Cosmic Microwave Background (CMB) studies.
- Optical/NIR telescope systems for Dark Matter and/or Exo-Planet studies.

Additionally, Astro2010 identifies optical components as key technologies needed to enable several different future missions, including:

- Light-weight X-ray imaging mirrors for future very large advanced X-ray observatories.
- Large aperture, light-weight mirrors for future UV/Optical telescopes.

The 2012 National Academy report "NASA Space Technology Roadmaps and Priorities" states that one of the top technical challenges in which NASA should invest over the next 5 years is developing a new generation of larger effective aperture, lower-cost astronomical telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects. To enable this capability requires low-cost, ultra-stable, large-aperture, normal and grazing incidence mirrors with low mass-to-collecting area ratios. To enable these new astronomical telescopes, the report identifies three specific optical systems technologies:

- Active align/control of grazing-incidence imaging systems to achieve < 1 arc-second angular resolution.
- Active align/control of normal-incidence imaging systems to achieve 500 nm diffraction limit (40 nm rms wavefront error, WFE) performance.
- Normal incidence 4-meter (or larger) diameter 5 nm rms WFE (300 nm system diffraction limit) mirrors.

Technical Challenges Technological developments at the telescope system level are required to enable higher capability measurements, longer duration flights and more affordable missions. The purpose of this sub-topic is to mature demonstrated component level technologies (TRL4) to demonstrated system level technologies (TRL6) by using them to manufacture complete telescope systems. Examples of desired technological advances relative to the current state of the art include, but are not limited to:

- Reduce the areal cost of telescope by 2X such that larger collecting areas can be produced for the same cost or current collecting areas can be produced for half the cost.
- Reduce the areal density of telescopes by 2X such that the same aperture telescopes have half the mass of current state of art telescope. Less mass enables longer duration flights.
- Improve thermal/mechanical wavefront stability and/or pointing stability by 2X to 10X.

Successful proposals shall provide a credible plan to deliver for the allocated budget a fully assembled and tested telescope assembly which can be integrated into a potential balloon mission to meet a high-priority NASA science objective. Successful proposals will demonstrate an understanding of how the engineering specifications of their telescope meets the performance requirements and operational envelop of a potential balloon science mission. Phase I delivery shall be a reviewed design and manufacturing plan which demonstrates feasibility. While detailed analysis will be conducted in Phase II, the preliminary design should address how optical, mechanical (static and dynamic) and thermal designs and performance analysis will be done to show compliance with all requirements. Past experience or technology demonstrations which support the design and manufacturing plans will be given appropriate weight in the evaluation. Phase II delivery shall be a completely assembled and tested optical telescope assembly ready to be integrated into a potential balloon mission. Testing shall confirm compliance of the telescope assembly with its requirements. **High Energy Telescope** A high-energy telescope is desired which includes the collecting optic, the structure which connects the collecting optic to the detecting instrument, and any mechanisms needed to maintain alignment and pointing stability of the collecting optic relative to the detecting instrument. Collecting optic should be able to collect and concentrate high-energy photons (above 10 keV). Collecting optics can be grazing incidence reflective, refractive or diffractive with a potential focal length ranging from 4 to 10 meters. Other 'optical' elements such as coded apertures can be considered. Angular resolutions should be significantly less than 1 arcminute for grazing-incidence optics, and ideally in the arcsecond range. Active control of the optic figure may be necessary. For refractive /diffractive optics, lower resolutions are acceptable, depending on energy. Effective collecting area should be greater than 10's cm² at 10 keV to enable useful data from typical balloon observing times. Higher energy 'optics' should provide enough area for a significant signal during flight. Optical assemblies must ideally be light weight to satisfy future mission demands. Total telescope mass budget goal is 200 kg. **Ultra-Stable 1-meter Class UVOIR Telescope** Potential Exoplanet balloon

studies require a complete optical telescope system with 1 meter or larger of collecting aperture to characterize exoplanets and dust disks over the range of wavelengths from 300 to 1100 nm, and ideally as long as 1600 nm. The telescope should be diffraction limited at 500 nm (< 36 nm transmitted wavefront) over a total field of view subtending at least 10 arc-seconds and over a field of regard extending from 20 to 70 ° elevation angle with respect to the gravity vector. The wavefront error power spectral density should monotonically decrease with increasing spatial frequency i.e., have no strong harmonics, from 0 to 30 cycles per aperture. Dynamic wavefront stability must be < 0.3 nm rms over timescales of 100s seconds and < 1 nm rms over timescales of 100s minutes. Sources of wavefront instability include thermal variations with boresight angle, thermal drift, coupling of residual vibration from reaction/momentum wheels, residual wind effects above 100,000 ft, and pointing induced beam shear. The telescope can achieve the stability requirement via either passive design or an actively controlled mirror (i.e., secondary mirror, fine steering mirror, deformable mirror, etc.). Possible telescope configurations include, but are not limited to, two mirror Cassegrain and Gregorian configurations, and 3 mirror anastigmat designs. Ideally the telescope is an unobscured off-axis system that can function with several different types of coronagraphs. But on-axis systems with simple secondary support spiders are allowed for a subset of possible high-contrast instruments. The telescope should form a centimeter scale real pupil image after the primary mirror vertex. The total telescope mass budget goal is 300 kg. **Low-Cost CMB Telescopes** Potential balloon measurements of CMB linear polarization desire complete 3 to 4 meter class off-axis telescope systems which are 2X lower areal cost and 2X lower areal mass than the current 2 meter class state of the art (as represented by the BLAST telescope) with the following optical, mechanical and operational requirements. Optical requirements:

- 3 meter to 4 meter diameter primary mirror.
- Diffraction-limited performance at 500 micron wavelength at 250 K.
- Wavefront stability of 15 micrometers rms per K.
- F/1 to F/1.5 primary mirror.
- 70 arc-minute field of view at 500 micron wavelength.
- Strehl ratio > 0.95 at edge of field of view.

Mechanical and operational requirements:

- Telescope to operate at ambient temperature 250 K (200 to 300K range).
- Telescope and mount to survive 10G shock (vertical).
- Telescope and mount to survive 5G shock (tilted 45 °).
- Mass of telescope to be 200 kg or less.
- Recurring production cost $< \$200$ K per telescope.

Successful proposals will deliver a complete preliminary design for the telescope at the end of Phase I and two to four complete telescope systems at the end of Phase II. **Low-Cost Far-Infrared Telescopes** Potential balloon Far-Infrared missions desire complete off-axis telescope systems which are 2X lower areal cost and 2X lower areal mass than the current state of the art with the following optical, mechanical and operational requirements. Optical requirements:

- 2.5 meter to 4 meter diameter primary mirror.
- Diffraction-limited performance at 100 micron wavelength at 250 K.
- Wavefront stability of 2.5 micrometers rms per K.
- F/1 to F/1.5 primary mirror.
- 15 arc-minute field of view at 100 micron wavelength.
- Strehl ratio > 0.95 at edge of field of view.

Mechanical and operational requirements:

- Telescope to operate at ambient temperature 250 K (200 to 300K range).
- Telescope and mount to survive 10G shock (vertical).
- Telescope and mount to survive 5G shock (tilted 45 °).
- Mass of telescope to be 200 kg or less.
- Recurring production cost $< \$200$ K per telescope.

Successful proposals will deliver a complete preliminary design for the telescope at the end of Phase I and two to four complete telescope systems at the end of Phase II. **Cryogenic Far-Infrared Telescope** Potential Far-Infrared balloon missions achieve significant improvements in sensitivity using cryogenic optics. Anticipated missions require a complete telescope system with larger collecting apertures and lower areal mass than the current state of the art. A cryogenic telescope is desired with 3 meter on-axis collecting aperture maintained at temperatures below 20 K. Low mass and long cryogenic hold time are particularly important. Optical requirements:

- Diffraction-limited performance at 300 micron wavelength at 20 K.
- F/1 to F/1.5 primary mirror.
- Field of view 20 arc-minutes minimum, 40 arc-min desired.
- Strehl ratio > 0.95 at edge of field of view.

Cryogenic requirements:

- Maintain entire telescope at 20 K or colder.
- Hold time 48 hours or longer, with goal of 21 days.

Mechanical requirements:

- Telescope and cryostat to survive 10G shock (vertical).
- Telescope and cryostat to survive 5G shock (tilted 45 °).
- Mass of telescope + cryostat to be < 1000 kg (goal 500 kg).

Successful proposals will deliver a preliminary design for the complete telescope and cryostat at the end of Phase I. Successful proposals will deliver the complete telescope and cryostat at the end of Phase II. **5 to 10 meter Segmented Far-IR Telescope** Potential Far-IR balloon studies required a complete optical telescope system with a 5 to 10 meter segmented aperture; 250 to 500 micrometer diffraction limited performance; wavefront stability of less than 10 micrometers rms; and a total mass of 400 (5m) to 800 kg (10m). **Heliophysics UVOIR Telescope** Potential Heliophysics studies require a complete optical telescope and/or camera system with: 1 to 2 meter collecting aperture, 20 ° field of view, 0.001 ° angular resolution and UV to Visible (120 to 700 nm) spectral range.